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Can the Speed of Light in the Fiber be Controlled?

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Summary

Nonlinear effects in optical fibers lead to many interesting phenomena, including nonlinear wave coupling, optical pulse compression, stimulated Raman and Brillouin scattering, harmonic generation, optical solitons etc. Solitons have been known to applied scientists for some 20 years (see for example [1]). In this work we predict that a nonlinear interaction between two copropagating modes and an acoustical wave in dual-mode optical fibers can lead to a three-wave envelope soliton (TWES) and controlling the speed of light in the fiber. To generate TWES, two light copropagating waves with slightly different frequencies have to be synchronously modulated and launched into the fiber as shown in Figure 1; the acoustical wave is generated in the fiber by nonlinear coupling with intermodal beating. The same second order nonlinearity is responsible for this process, it is similar to the stimulated forward Brillouin scattering [2]. TWES's are similar to "conventional" optical solitons [3] in the sense that they are envelope solitons. However, unlike "conventional" optical solitons, TWES is a nonlinear combination of three waves [4].

For fiber parameters given in Table 1, TWES's exist if the length of the fiber is between 10^2 and 10^3 m. The upper limit is imposed by the light attenuation in the fiber and the lower limit is imposed by the maximum available pump power ($\sim$ 100 mW) for a pulse duration of hundreds of μsec's. The minimum pump power of $\sim$ 1 mW is limited by the sound wave attenuation. Suitable durations of the launched light pulses is between 0.1 and 1 msec. The lower limit is determined by the spatial width of the soliton (which must be shorter than the fiber length). The upper limit is imposed by the condition of small attenuation of the sound wave.

Perhaps the most interesting feature of TWES's is the fact that their velocity depends on the power of the pump wave [5]. Thus, one can control the velocity of the solitons by adjusting the pump power. The dependence of the soliton velocity on the pump power is shown in Figure 2. The curve in Figure 2 consists of two parts corresponding to slow and fast solitons. For slow solitons, $V_s \leq V \leq 2 \times V_s$; V, V_s, and V_l designate soliton, sound, and light velocities; for fast solitons, $2V_s \leq V \leq V_l$. Computer simulations show [5] that laser injection generates only a fast TWES with a velocity much larger than the velocity of sound. It can be shown that the parameters of TWES for the case of fast solitons with $V_s \ll V \ll V_l$ are interrelated as follows:

$$V = V_l \frac{\tau_{NL}^2}{\delta^2}, \quad \Delta = V_l \tau_{NL} \frac{\tau_{NL}}{\delta}, \tag{1}$$

where $\tau_{NL} = 1/\alpha_1 \alpha_3 A_0^2$ is a square of nonlinear time scale determined by the amplitude of the electric field A_0 of the pump and nonlinear coefficients $\alpha_{1,3}$ [5], Δ is the spatial length of the soliton. The inverse dependence between the temporal δ and the spatial Δ scales clearly demonstrates nonlinear nature of TWES.

Our analysis shows that by simulteneously adjusting the pump power between 100 mW and 1 mW and the time duration δ between 0.1 and 1 msec, the light velocity can be adjusted between the upper limit of 2×10^{10} cm/sec (which is the speed of a linear light wave in the fiber) and the lower limit of 10^7 cm/sec (which is the minimal speed of the soliton which is not heavily attenuated during travelling time through the fiber).

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TABLE 1. Parameter Values Assumed.

Parameter	Value	Units
Sound Velocity	3×10^5	cm/sec
Maximum Pump Power	100	mWatts
Laser Wavelength	1.3	μm
Photoelastic Constant	0.2	Dimensionless
Overlapping Integral	1	Dimensionless
Fiber Density	2.2	g/cm^3
Refractive Index	1.5	Dimensionless
Refractive Index Difference Between Two Modes	5×10^{-3}	Dimensionless
Fiber Core Diameter	8	μm
Sound Wave Frequency	11	MHz
Sound Wave Attenuation	8	msec

References

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FIGURE CAPTIONS

Fig. 1. A sketch of the laser waves at the input to the fiber.

Fig. 2. The TWES speed versus the pump power for the fast solution (the shadow line) and the slow solution (the solid line). The temporal width of the soliton is equal to 300 μsec.

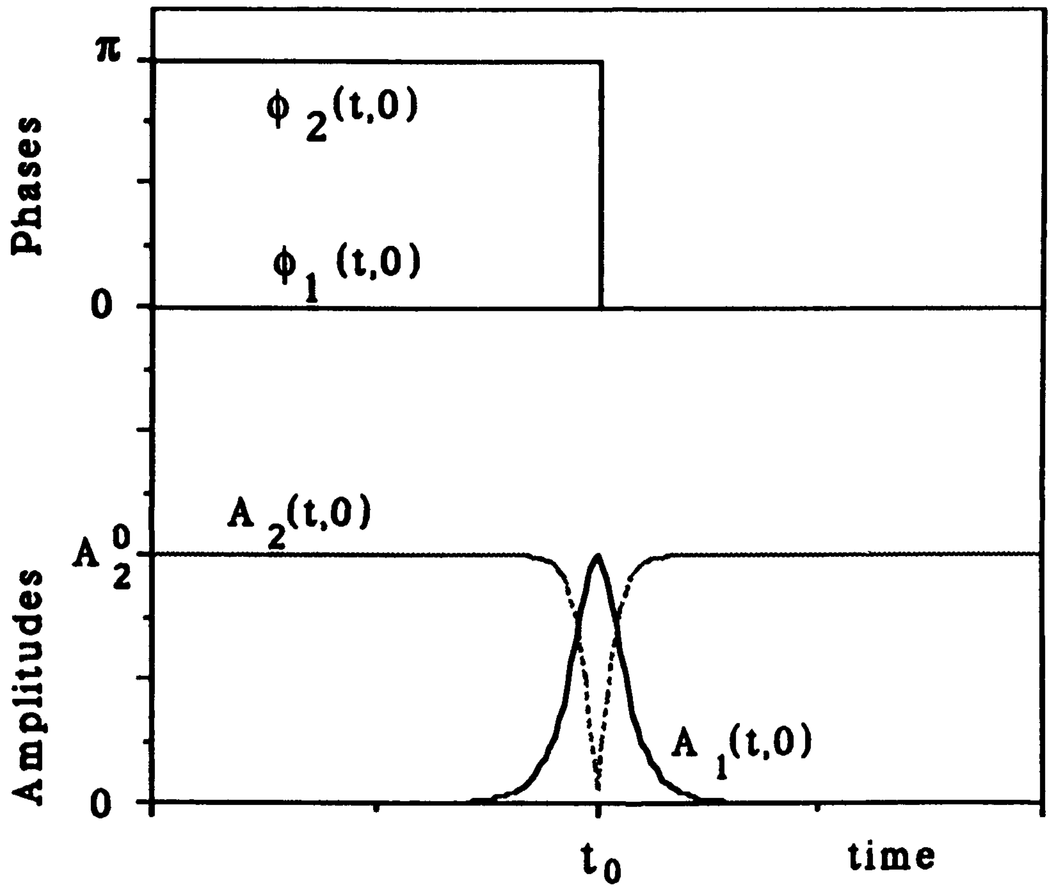
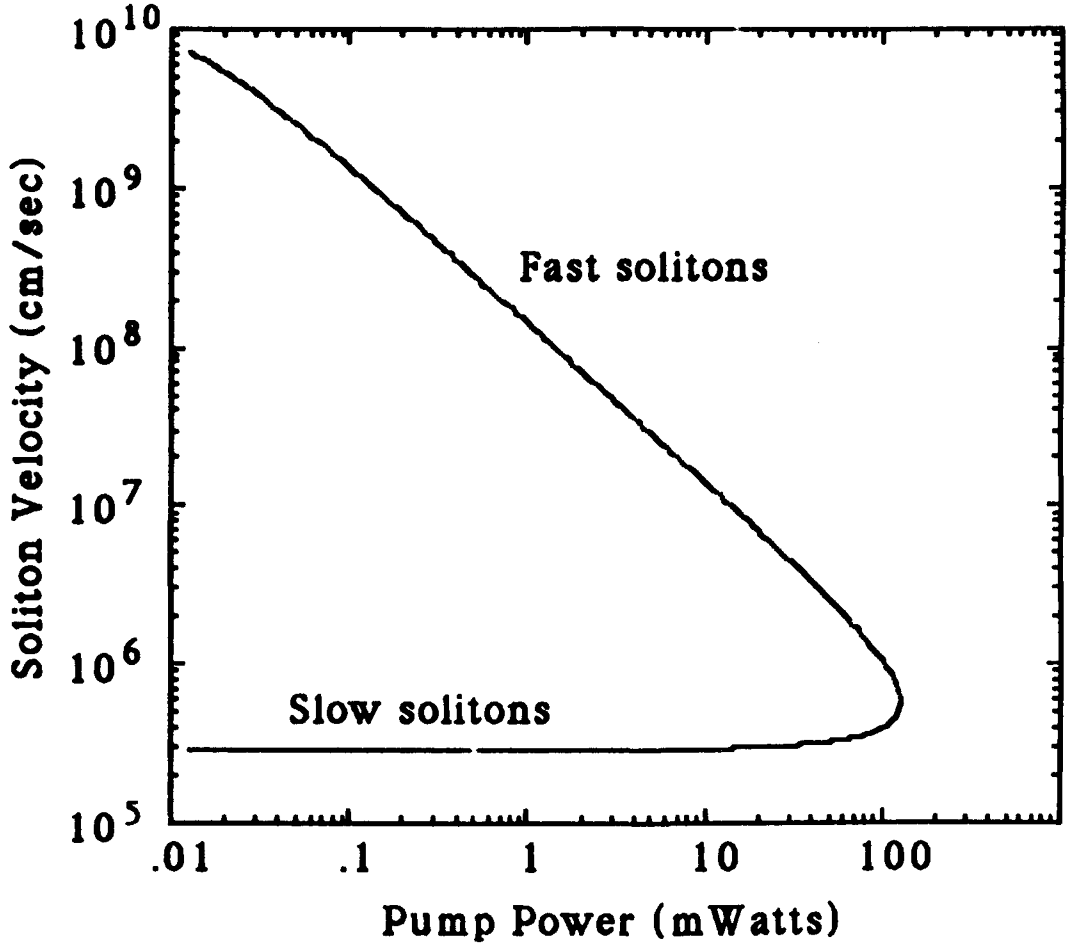


Figure 1



10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
Soliton Velocity (cm/sec)
Fast solitons
Slow solitons
.01
.1
1
10
100
Pump Power (mWatts)

Figure 2